

teresis—or path dependency—of the SMA member 22 may be reduced by adding, for example, copper to alloys of Nickel and Titanium. In embodiments or configurations where the SMA member 22 includes multiple strands or SMA elements (such as multiple springs), different individual alloys may be used to build the SMA member 22, such that the heat engine 14 is built to simultaneously operate over a broad range of operating temperatures.

[0097] The SMA member 22 may be formed from thin, straight SMA wire, on the order of, for example, 0.05-0.3 millimeter. Thin-wire may be a relatively inexpensive form of SMA to produce, and produces good operating properties (fatigue, power output). Heat transfer per mass of SMA is relatively high when the SMA member 22 is formed from thin-wire SMA. Increased heat transfer allows the heat engine 14 to cycle material more quickly, especially with a convection heat source as the hot region 18.

[0098] The SMA member 22 may be formed as a continuous loop without joints, or as a single loop element having a single joint forming the straight, thin wire into the continuous loop. Alternatively, a single wire may be looped multiple times around the path defined by the pulley members, but still have only one joint. The exact diameter of the thin-wire SMA forming the SMA member 22 may be varied based upon the operating conditions of the heat engine 14, such as, without limitation: the first temperature of the hot region 18 and the second temperature of the cold region 20; the amount of strain introduced in the SMA member 22 during expansion and travel around the loop; the operating frequency of the heat engine 14; and the predicted lifecycle of the SMA member 22 or the heat engine 14.

[0099] Forming the SMA working element into a loop may require one or more joints in the SMA member 22. The joint may be created through laser welding the two ends of the SMA working element together.

[0100] Welding processes may re-melt the material and create non-uniform grain structure. Post processing of the joints may improve the resulting ultimate tensile strength and cyclic fatigue characteristics of the SMA member 22. Removing the non-uniform grain structure may reduce the likelihood of dislocation collecting and reduce fatigue fractures in the SMA member 22. Post processes of the SMA member 22 may include, but are not limited to: annealing, drawing, rolling, swaging, and varieties of thermo-mechanical processing combinations.

[0101] Referring now to FIG. 5A, FIG. 5B, and FIG. 5C, and with continued reference to FIGS. 1-4, there are shown schematic fragmentary cross-sectional views of additional SMA working element forms. The working elements shown are manufactured or assembled as bands, which have greater width-to-thickness ratios than wires.

[0102] FIG. 5A shows an SMA member 122 that is formed from parallel wires, strips or strands 123 of thin-wire SMA. FIG. 5B shows an SMA member 162 that is formed from parallel wires, strips or strands 163 of thin-wire SMA that are partially-embedded within a matrix 166. FIG. 5C shows a composite SMA member 192 that is formed from multiple units of a smaller SMA member.

[0103] FIGS. 5A, 5B, and 5C represent additional SMA working element forms that may be used with various types and configurations of heat engines, such as those shown and described herein. Features and components shown and described in other figures may be incorporated and used with those shown in FIGS. 5A, 5B, and 5C.

[0104] FIG. 5A shows tack welds 124, which join the parallel strands 123 to form the SMA member 122. Alternatively, the parallel strands 123 may be joined by localized, interlocking deformations which mechanically link the parallel strands 123 without the heating processes involved in welding. Although not shown, the parallel strands 123 may also be free, such that each strand 123 is not joined to the others. A pulley 140 is schematically shown to demonstrate contact between the SMA member 122 and the drive pulleys of the heat engine into which the SMA member 122 is incorporated.

[0105] Generally, the cross-sectional shape of the strands 123 shown is round. However, the thin-wire SMA strands 123 may be formed with other cross sections, such as, without limitation: square, rectangular, oval, box-beam, or I-beam. The other shapes of SMA strands 123 may also be formed into bands.

[0106] FIG. 5B shows that the SMA member 162 is formed from the SMA strands 163 arranged into a mat or band formation and then into a continuous loop. An outer portion (relative to the pulley 140, which is shown schematically) of the strands 163 is collectively coated or embedded by an elastomer to form the matrix 166.

[0107] The matrix 166 keeps the individual strands 163 separate and also conducts heat from the strands 163. However, the matrix 166 does not come directly into contact with the pulley 140, so that the matrix 166 is not compressed between the pulley 140 and the strands 163. Additionally, the partial matrix may better handle the dynamic (size-changing) relationship between the strands 163 and the matrix 166.

[0108] The elastomer forming the matrix 166 may be intrinsically thermally conducting or may be filled (or doped) with materials to enhanced heat conduction. These fillers may include metal or carbon/graphite wires, microwires, and non-wires as well as other high aspect-ratio fillers like platelets. The matrix 166 may be placed into direct contact with the heat source to conductively draw heat into the strands 163 in the hot region. Similarly, the matrix 166 may assist in expelling heat to the cold region by conducting heat from the strands 163 and convectively or conductively communicating that heat to the cold region.

[0109] The SMA members 122, 162 shown in FIGS. 5A and 5B are illustrated with only four strands 123, 163. However, many more strands 123, 163 may be used in forming the SMA members 122, 162 into wider bands (having greater width-to-thickness ratios).

[0110] In large-scale heat engines, the added width, thickness, length, and (possibly) number, of SMA working elements may require multiple idler pulleys to maintain tension and take up slack in the SMA working elements. For example, and without limitation, a bricklayer pattern may be used with multiple units to build up, in a staggered fashion, to a larger and stronger composite SMA working element. While single, thin-wire working elements may be efficient in small-scale operations, it may not be practicable to simply enlarge the single wire for large-scale energy production from the heat engines. Larger, stronger, and more durable SMA working elements may better allow the heat engines into which the SMA working elements are incorporated to produce substantial energy outputs.

[0111] Note that while FIG. 5B shows only individual thin-wire SMA strands 163, the matrix 166 may also be used with braids, meshes, or weaves of SMA. With weaves or meshes, for example, the matrix 166 would be applied after assembly of the weave or mesh and would still be located away from the